

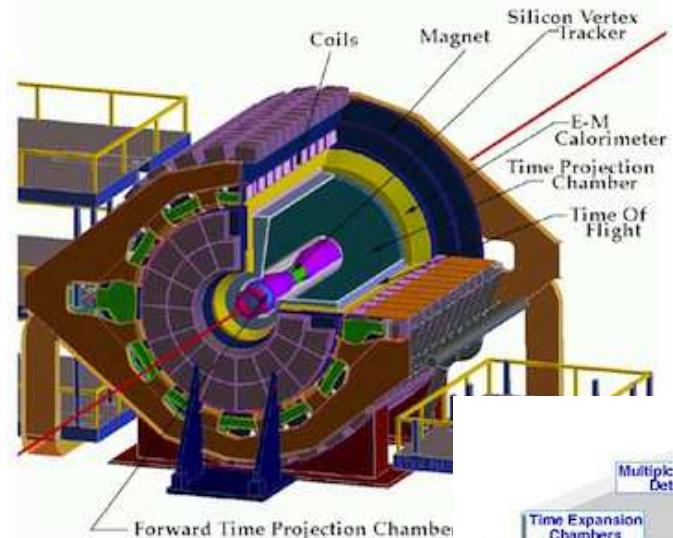
Measuring Polarization of Proton Beams at RHIC

Dmitri Smirnov
Brookhaven National Laboratory

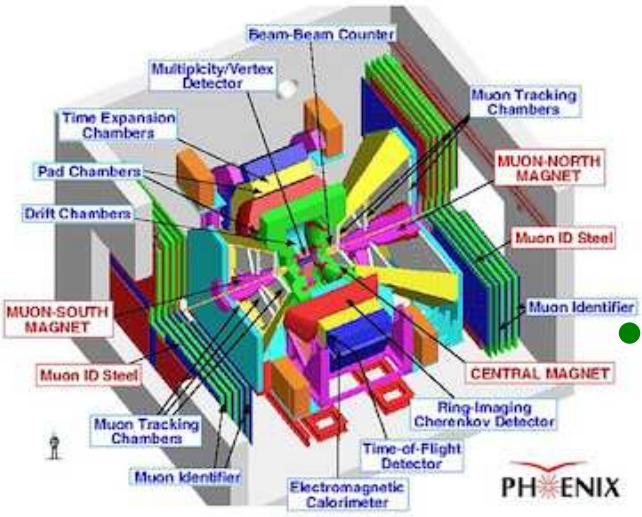
for the RHIC Spin Group

June 10, 2011

Physics Objectives and Facilities



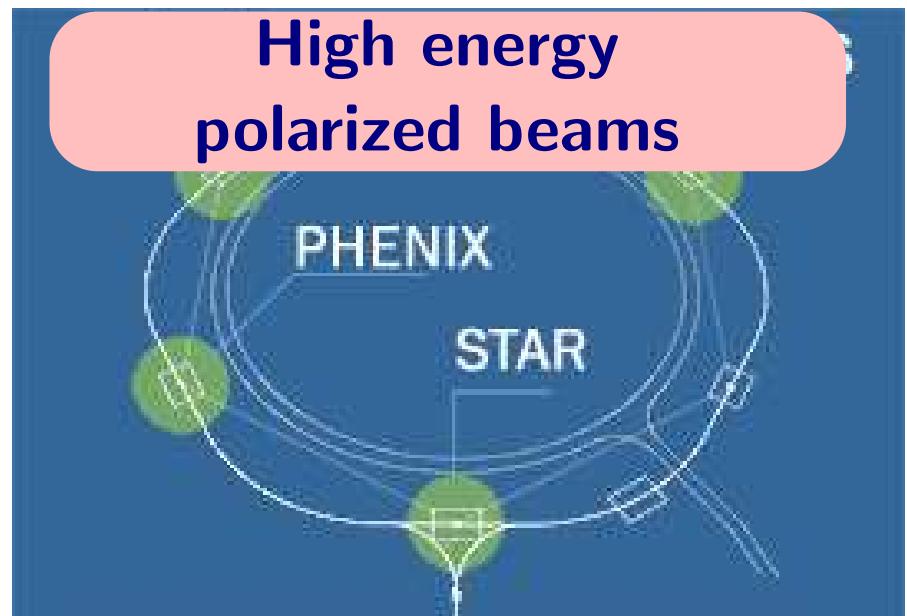
- Two operational detectors STAR and PHENIX
- Measure transverse and longitudinal spin asymmetries
- Understand gluon polarization in the proton spin structure



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta L + \Delta g$$

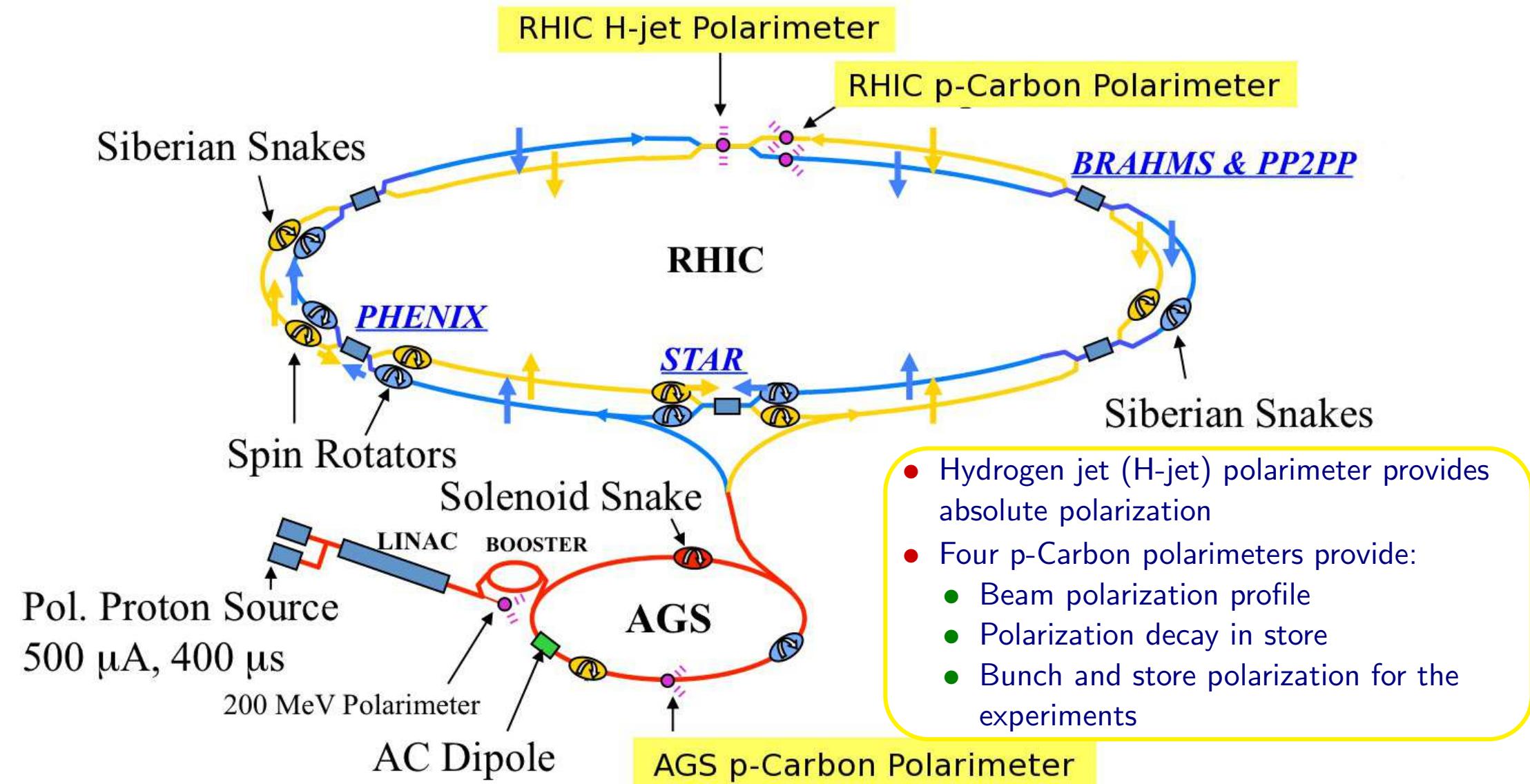
- quark and gluon contribution: $\Delta\Sigma \sim 0.25$, $\Delta g - ?$,
orbital motion: ΔL
- Study quark-gluon plasma

**High energy
polarized beams**



- Relativistic Heavy Ion Collider (RHIC) operational since 2000
- Provides polarized proton beams
- Wide range of energies 24 GeV to 250 GeV
- Also unpolarized heavy ion beams
Au-Au, d-Au, Cu-Cu

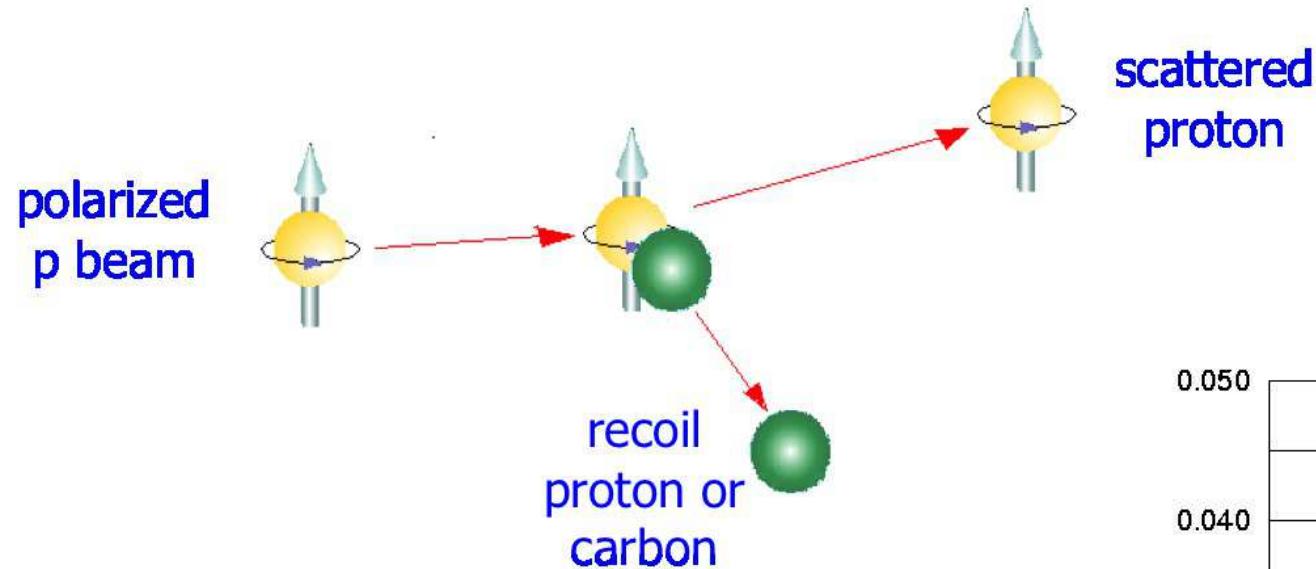
RHIC and AGS Polarimeters



- Polarimeter at Alternatig Gradient Synchrotron (AGS) is similar to RHIC p-Carbon polarimeter
 - PHENIX and STAR local polarimeters monitor spin direction at collision points

Measuring Beam Polarization

- The kinematics of elastic scattering is fully defined by the recoil products
- The momentum transfer $t = (p_{\text{in}} - p_{\text{out}})^2 = -2ME_{\text{kin}}$

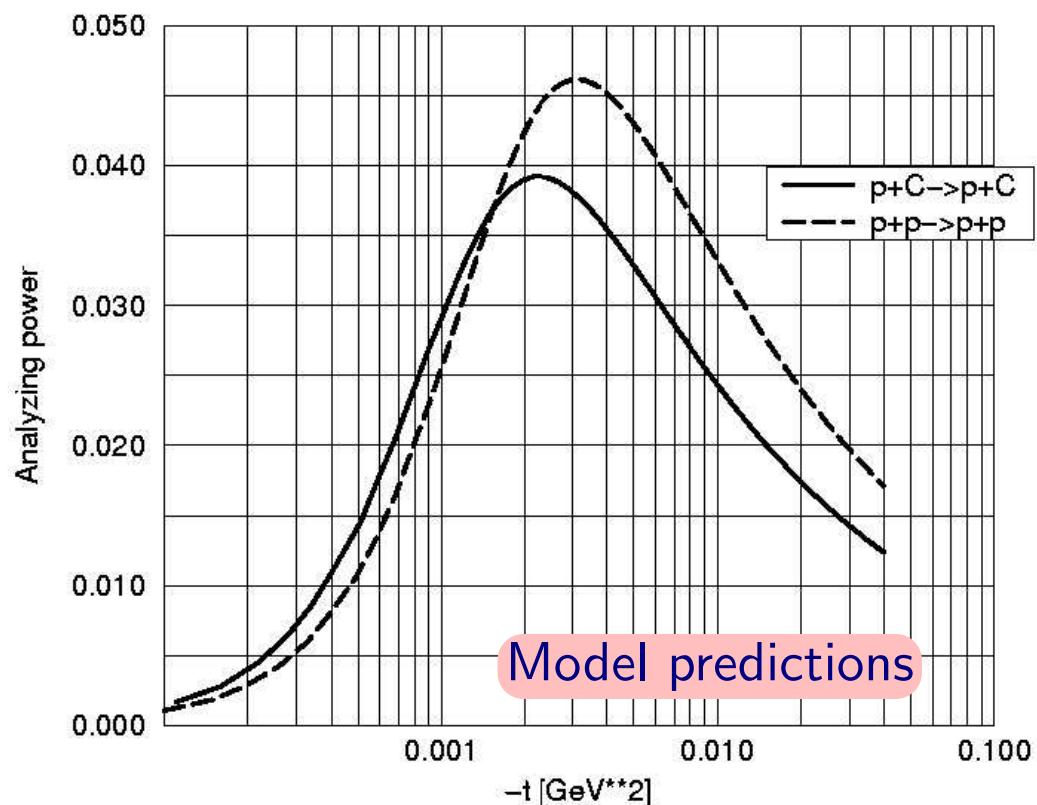


Analyzing power A_N is defined by the interference between the electromagnetic and strong amplitudes

- In the experiment we measure asymmetry ε

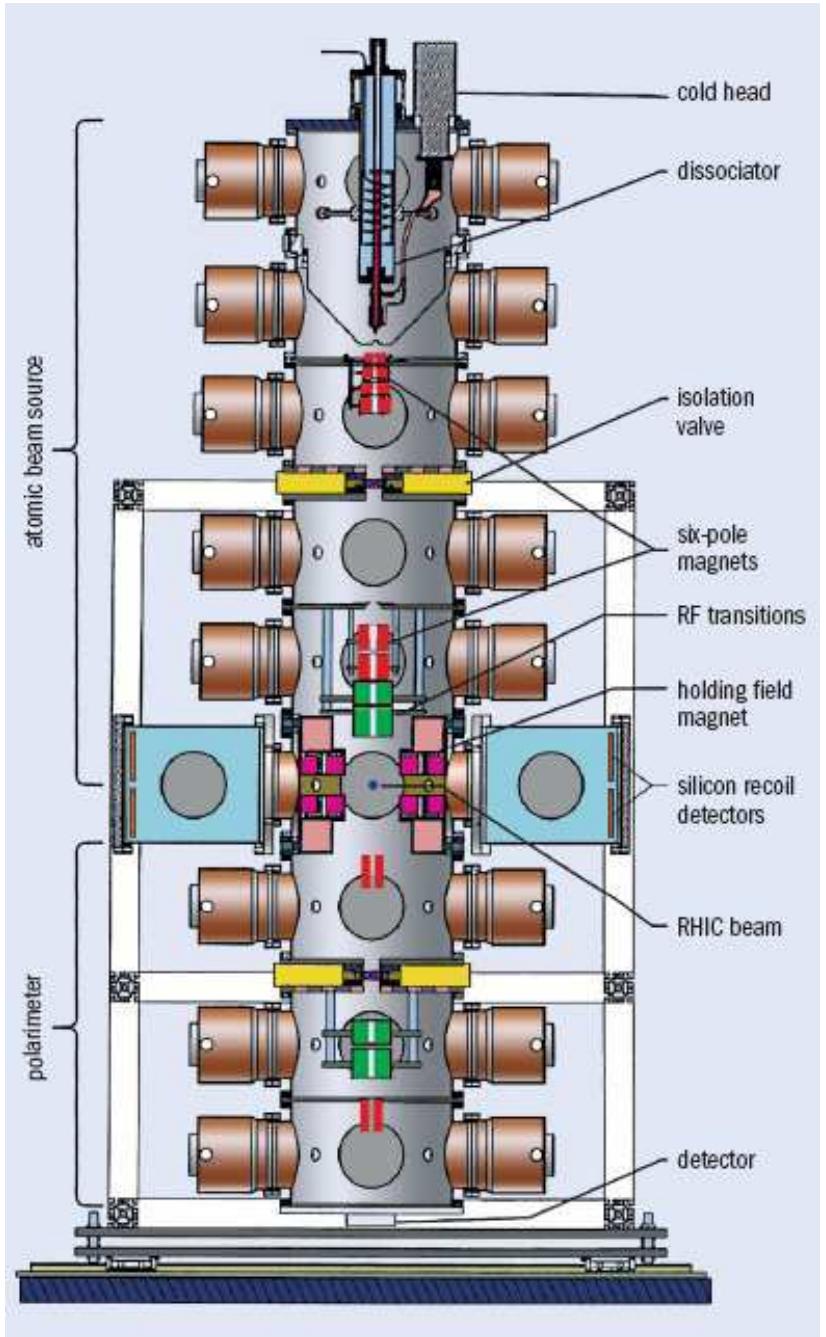
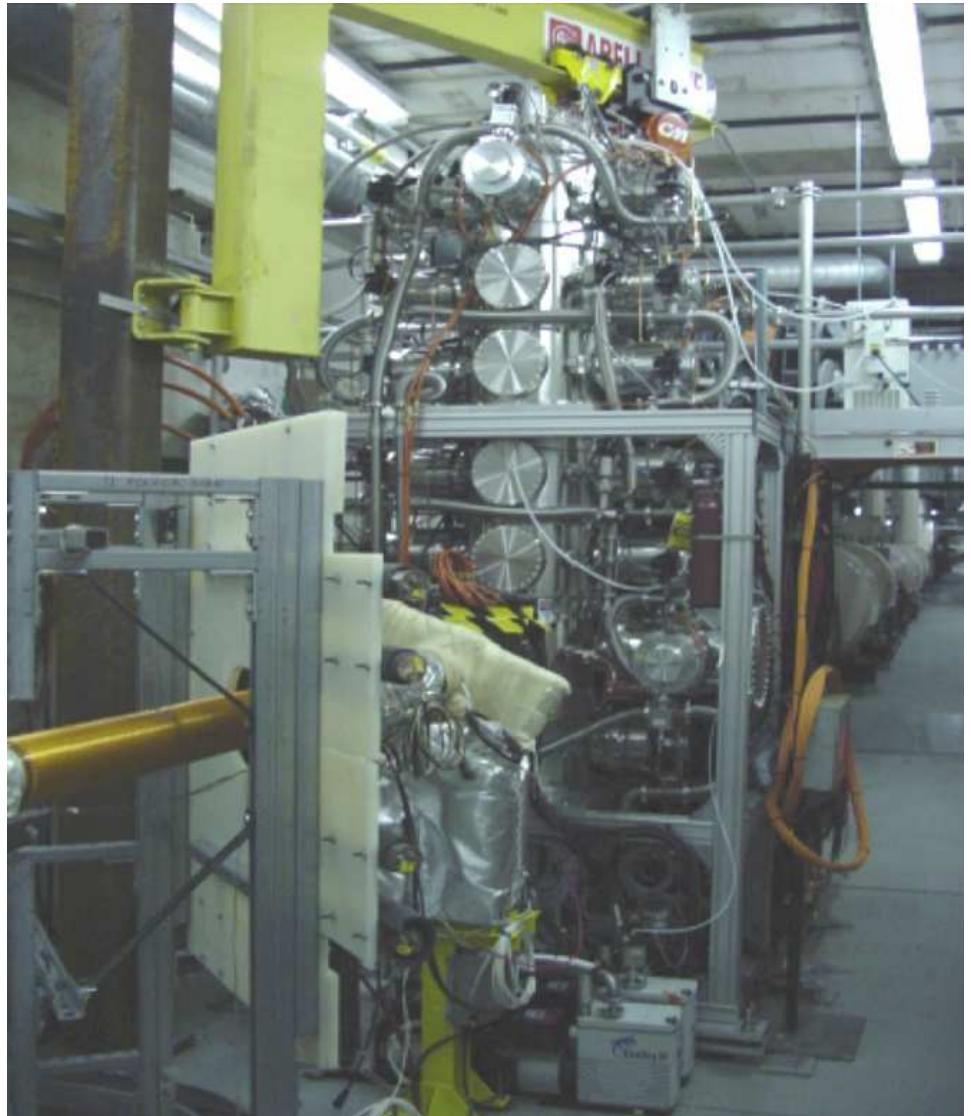
$$\varepsilon = \frac{N_L - N_R}{N_L + N_R}, \quad \varepsilon = \frac{N^\uparrow - N^\downarrow}{N^\uparrow + N^\downarrow}$$

- Measured polarization $P = \varepsilon/A_N(t)$, where $A_N(t)$ is the **analyzing power**



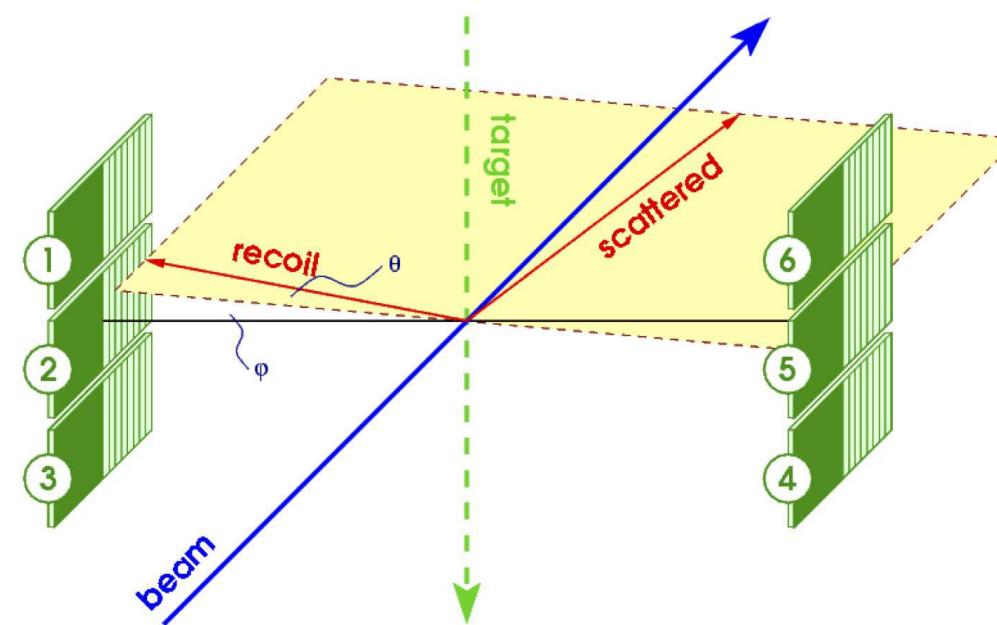
Model predictions

Hydrogen Jet Polarimeter



- The polarized jet target is vertical
- Target polarization cycles $\uparrow / - / \downarrow$ every 500/50/500 seconds

Hydrogen Jet Polarimeter: Kinematics



- Elastic events are easily identified from non-relativistic equation

$$t_{\text{TOF}} = L \sqrt{\frac{m_p}{2E_{\text{kin}}}}$$

and recoil angle Θ

- Asymmetry $\varepsilon = \frac{N_L - N_R}{N_L + N_R}$

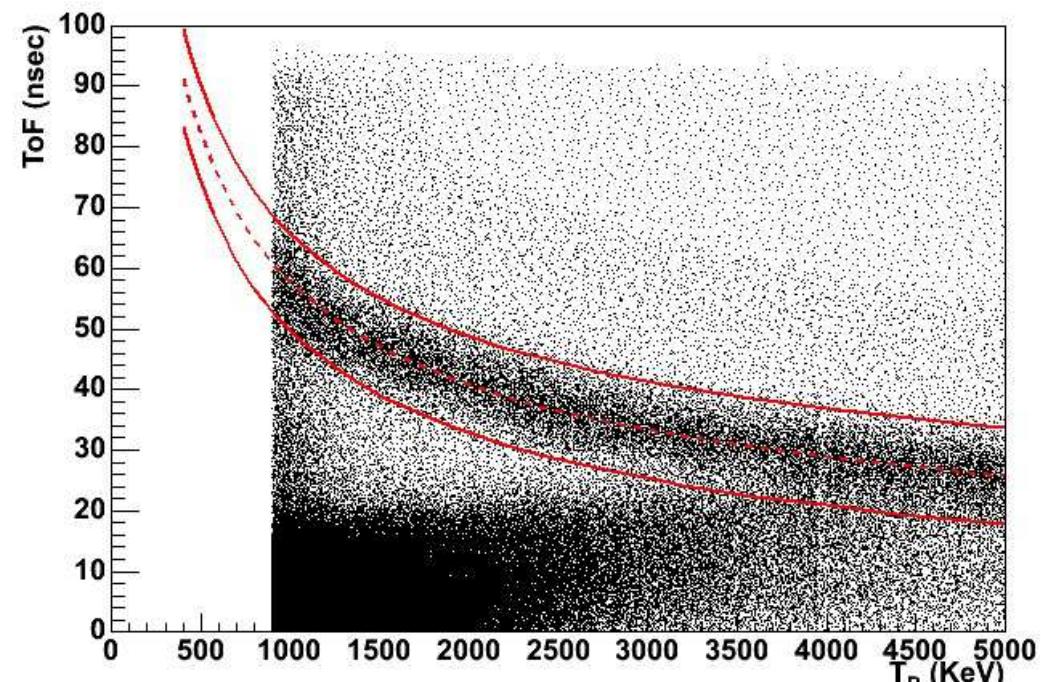
- Both beams separated by ~ 4 mm intersect the hydrogen jet target

- The beam and the target are both protons:

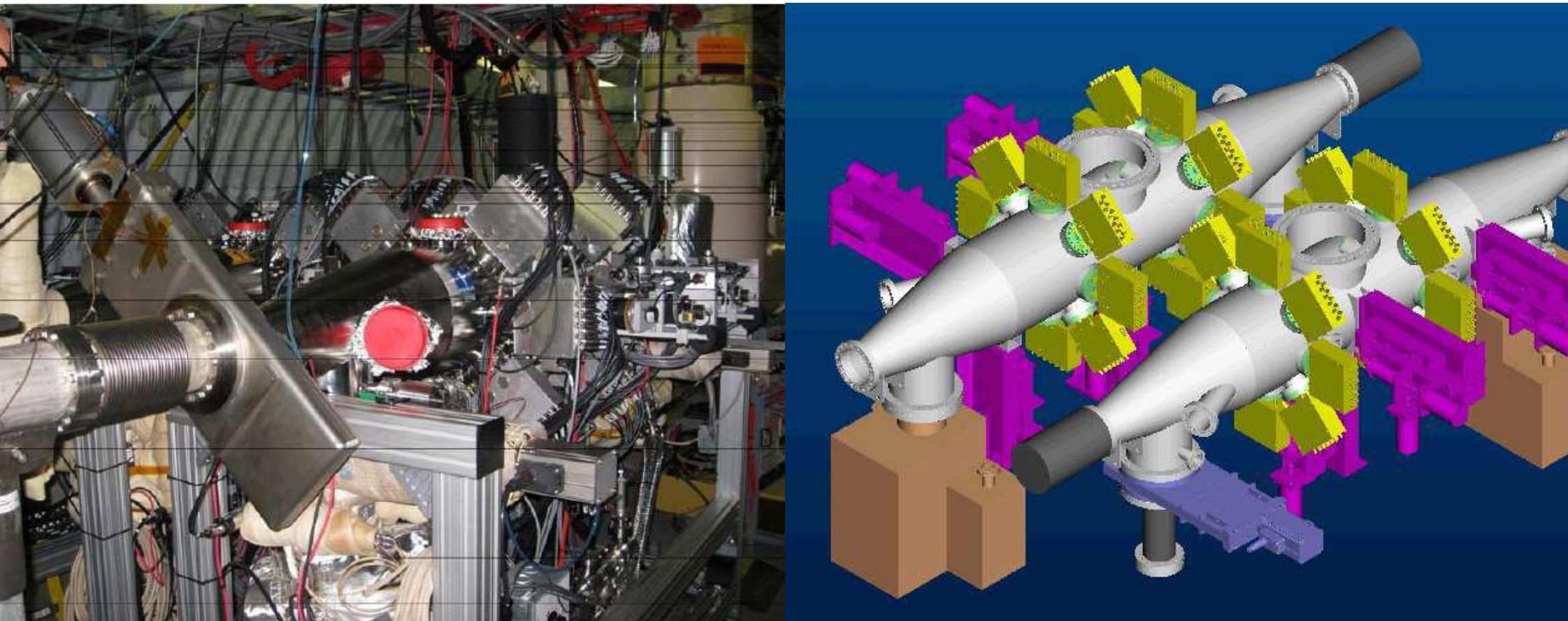
$$P_{\text{beam}} = -\frac{\varepsilon_{\text{beam}}}{\varepsilon_{\text{target}}} \times P_{\text{target}}$$

- P_{target} is measured by a Breit-Rabi polarimeter
- After correction for molecular contamination in the jet

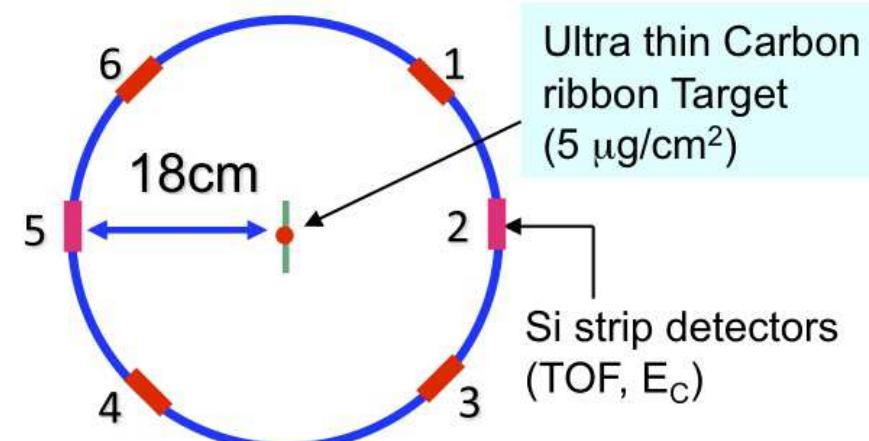
$$P_{\text{target}} \approx 92 \pm 2\%$$



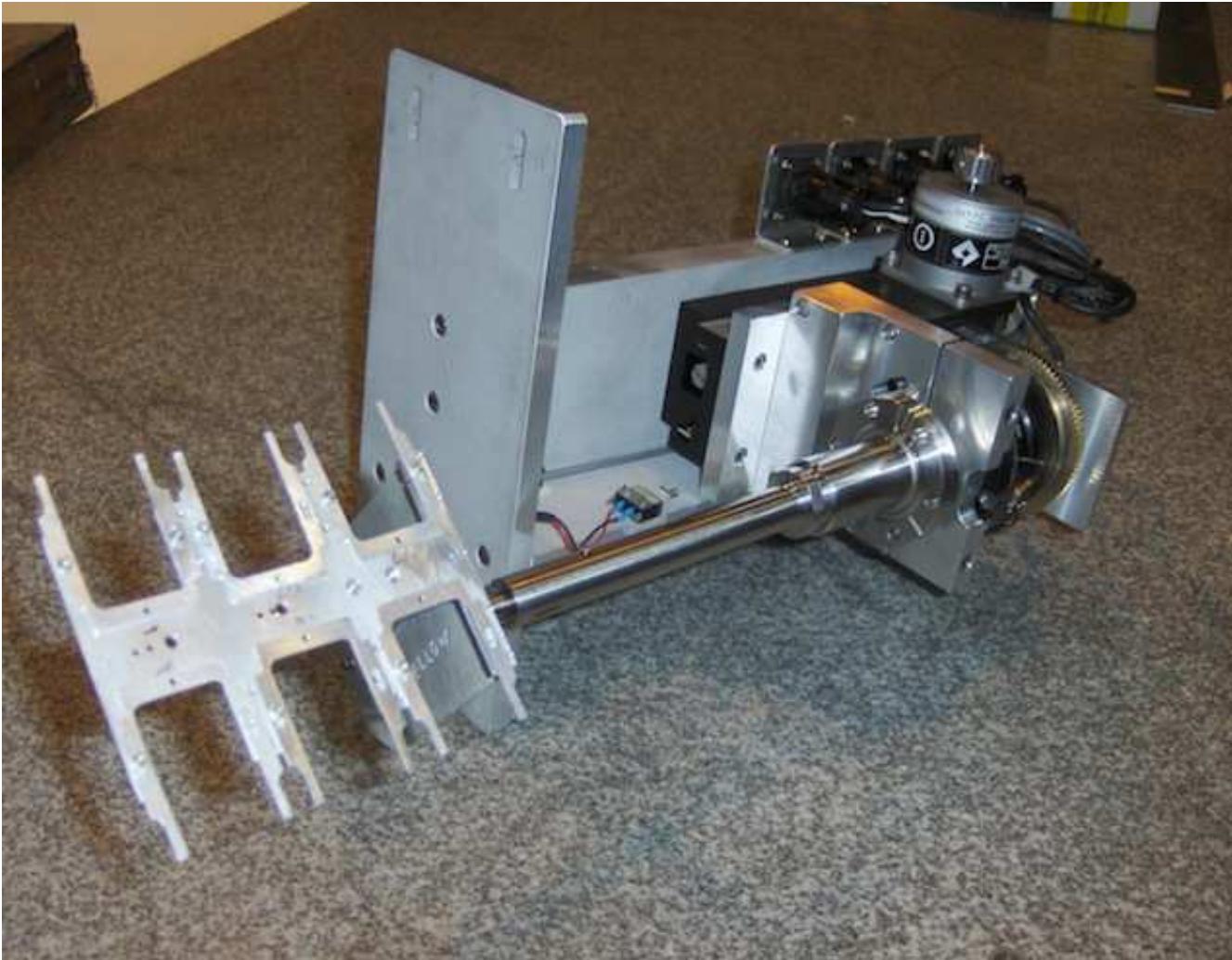
p-Carbon Polarimeters



- Two polarimeters in each ring
- The readout system is multiplexed between the two pairs
- Each polarimeter employs six vertical and six horizontal ultra thin carbon targets



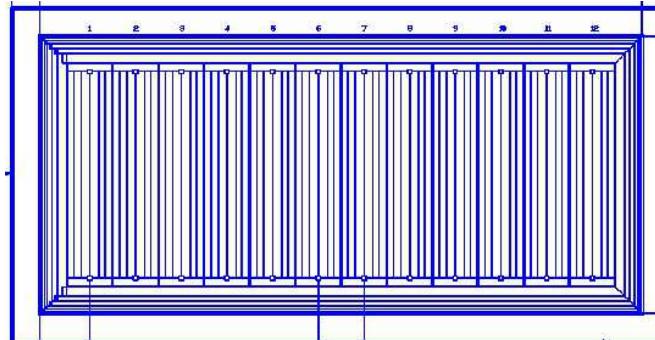
p-Carbon Polarimeters: Targets



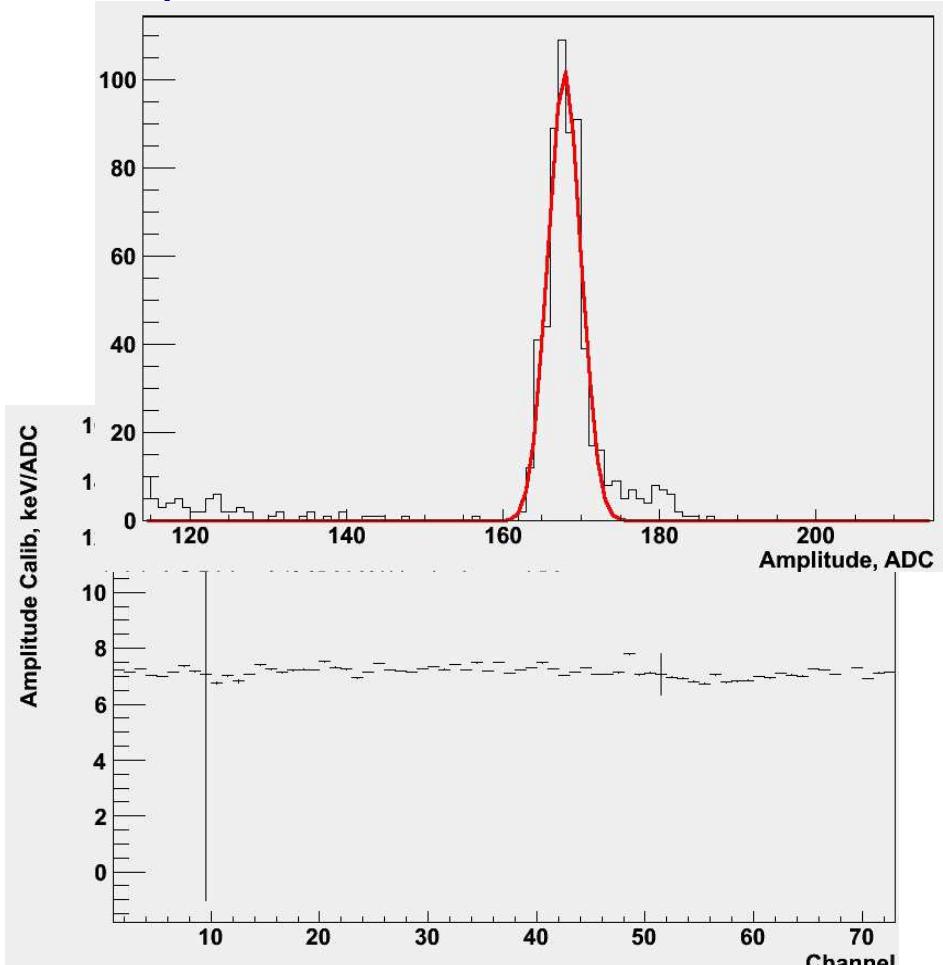
- Typical target size is $2.5\text{cm} \times 5\mu\text{m} \times 30\text{nm}$
- Targets are made by vacuum evaporation-condensation onto glass substrate
- Two stepping motors are used to move the assembly and to rotate the targets into the beam

p-Carbon Polarimeters: Detector Calibration

9 of 18

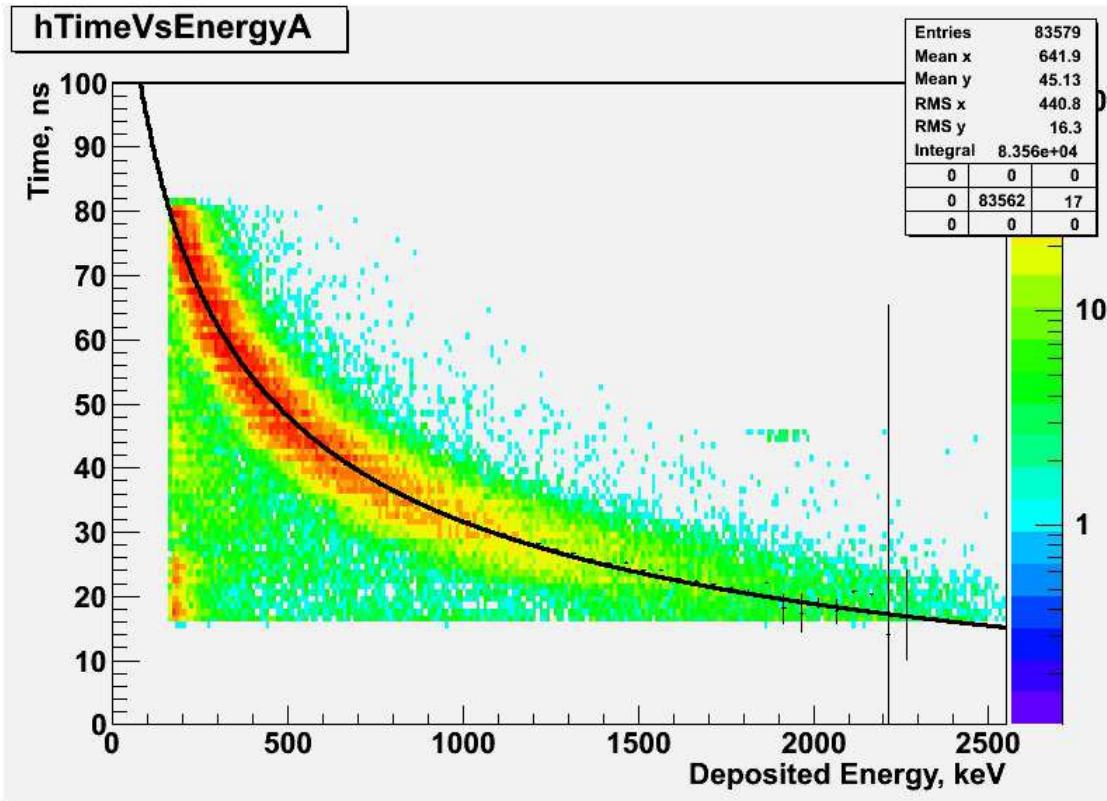


12 strips 2×10 mm



- Detectors calibrated with α source (^{241}Am , 5.5 MeV)
- The α signal is attenuated by 5 to fit the carbon dynamic range
- The α 's do not probe the surface of the detector where the carbon ions stop
Unaccounted energy losses \Rightarrow “effective dead-layer”

p-Carbon Polarimeters: Kinematics



- Calibration parameters the **time offset** t_0 and the **effective dead layer thickness** x_{DL} extracted from the non-relativistic equation:

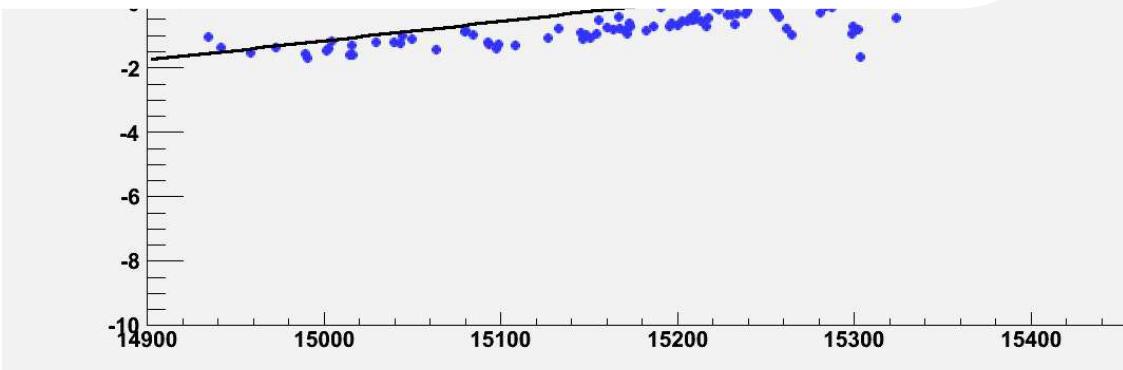
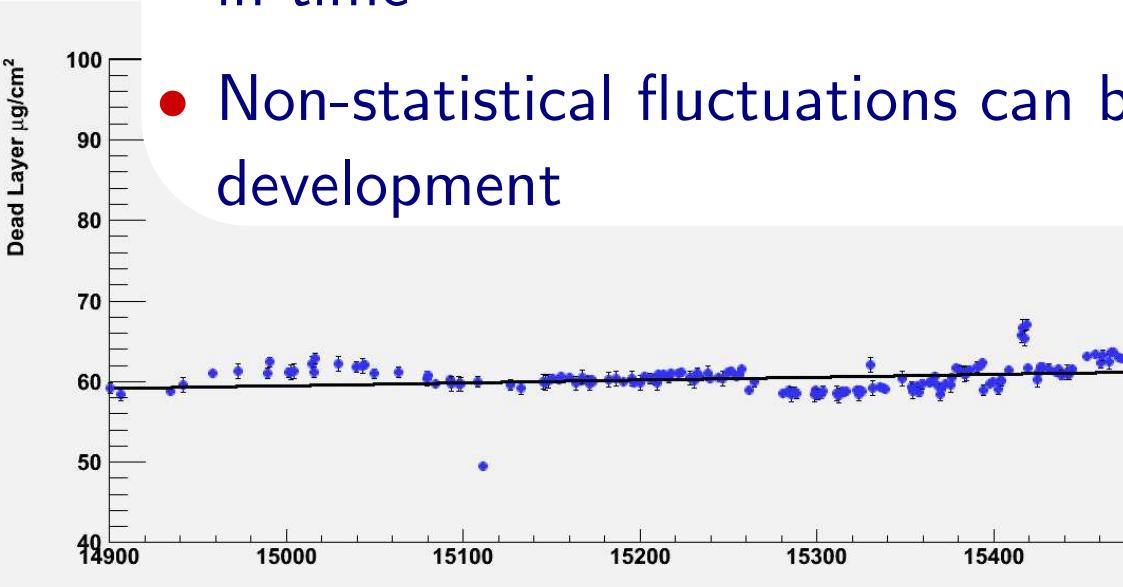
$$E_{\text{meas}} + E_{\text{loss}} = \frac{M_C}{2} \times \frac{L^2}{(t_{\text{meas}} + t_0)^2},$$

where $E_{\text{loss}} = E_{\text{loss}}(E_{\text{meas}}, x_{DL})$ is a energy loss parameterization for carbon

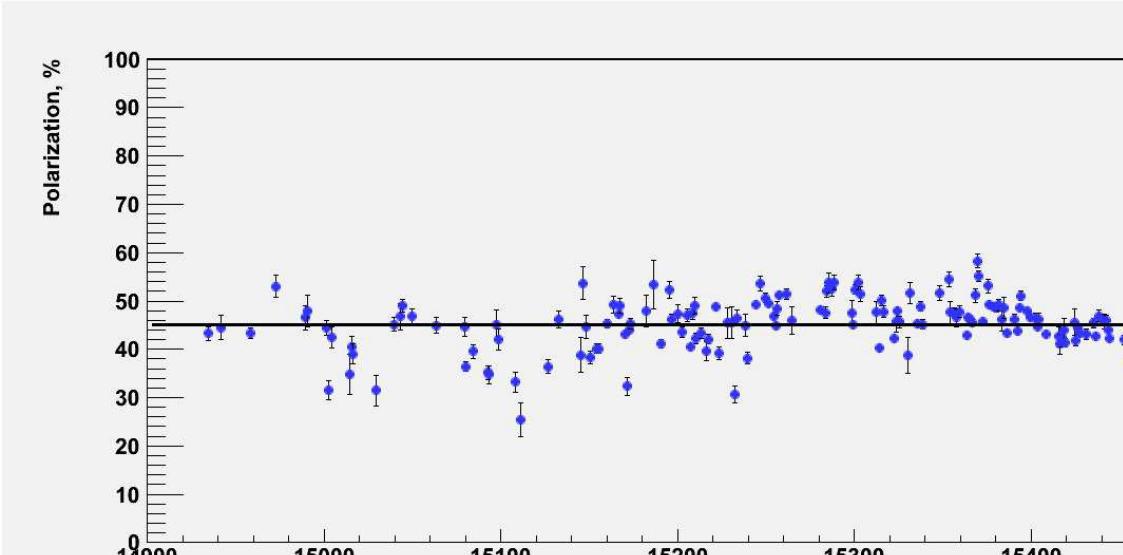
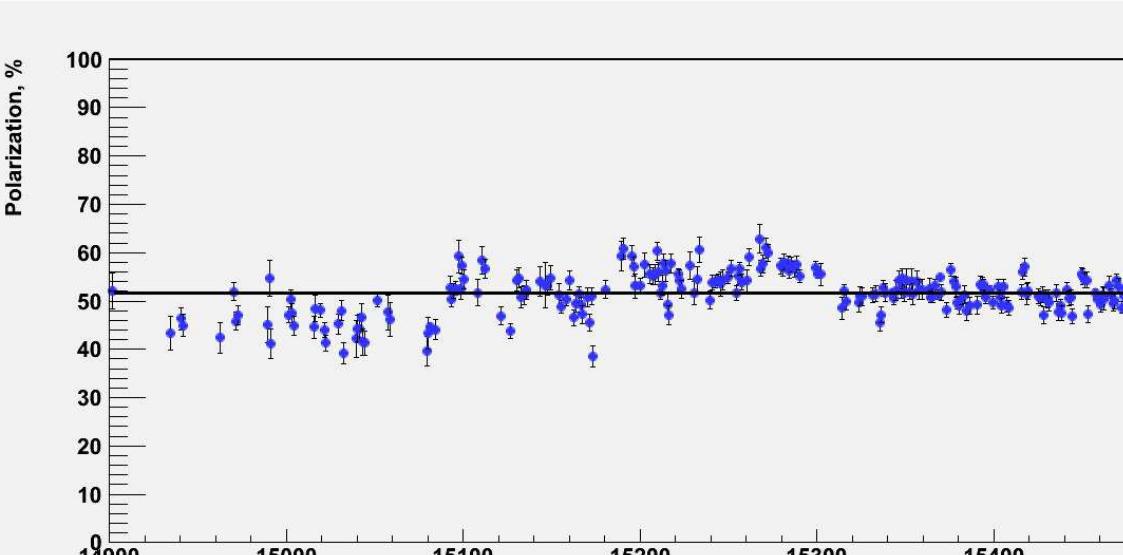
p-Carbon Polarimeters: Monitoring Stability

11 of 18

- Detector stability is monitored by looking how the parameters evolve in time
- Non-statistical fluctuations can be associated with machine development

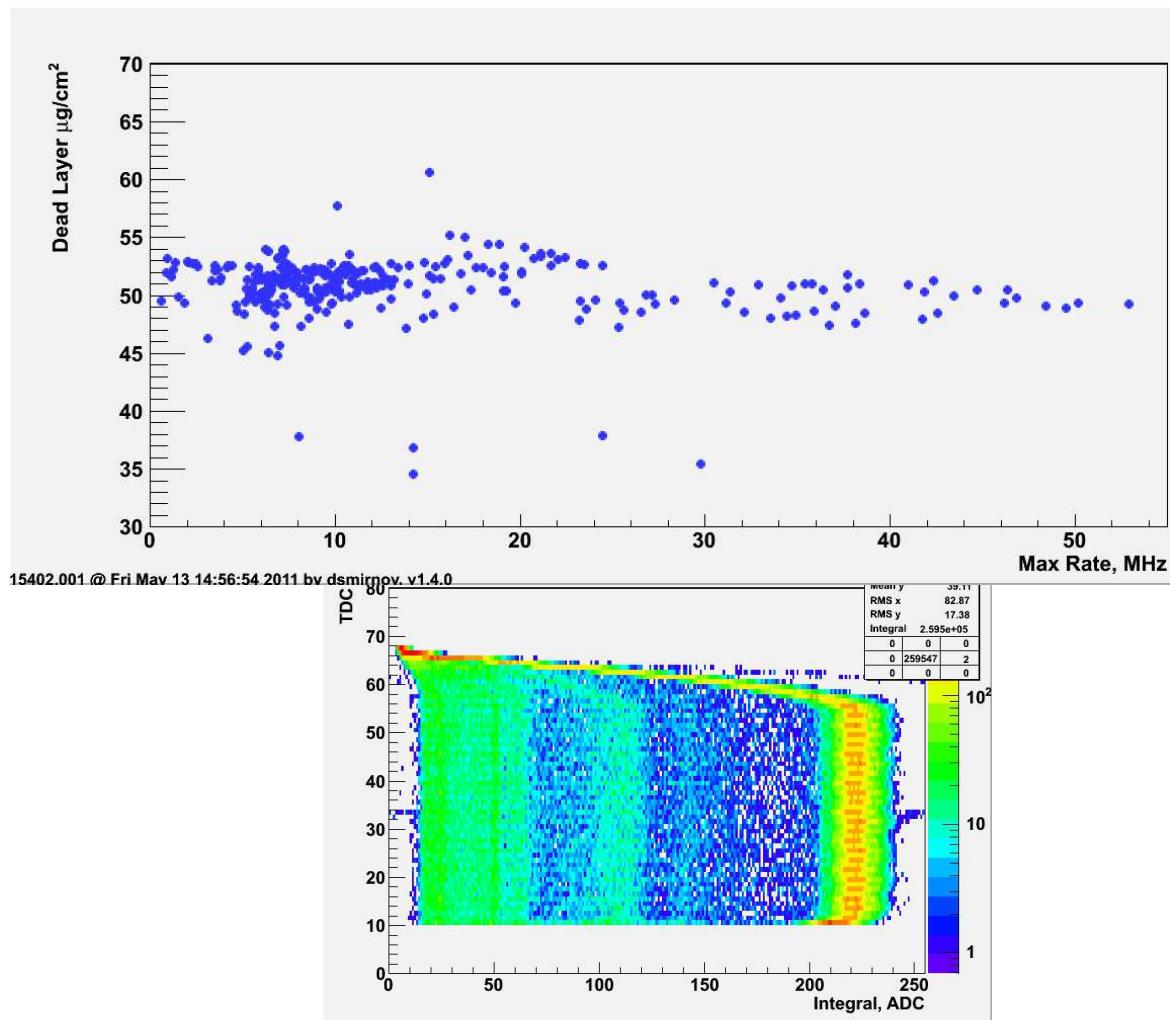
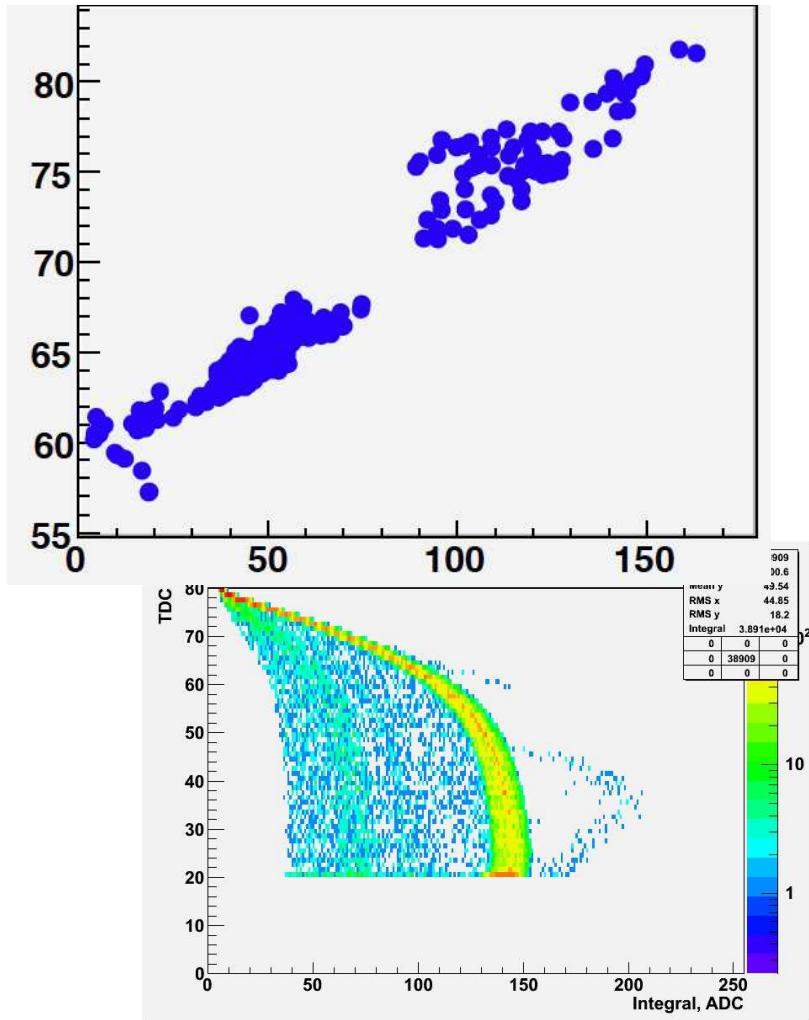


- Based on the reconstructed kinematics we measure beam polarization



Solving Problems: Event Pile-up

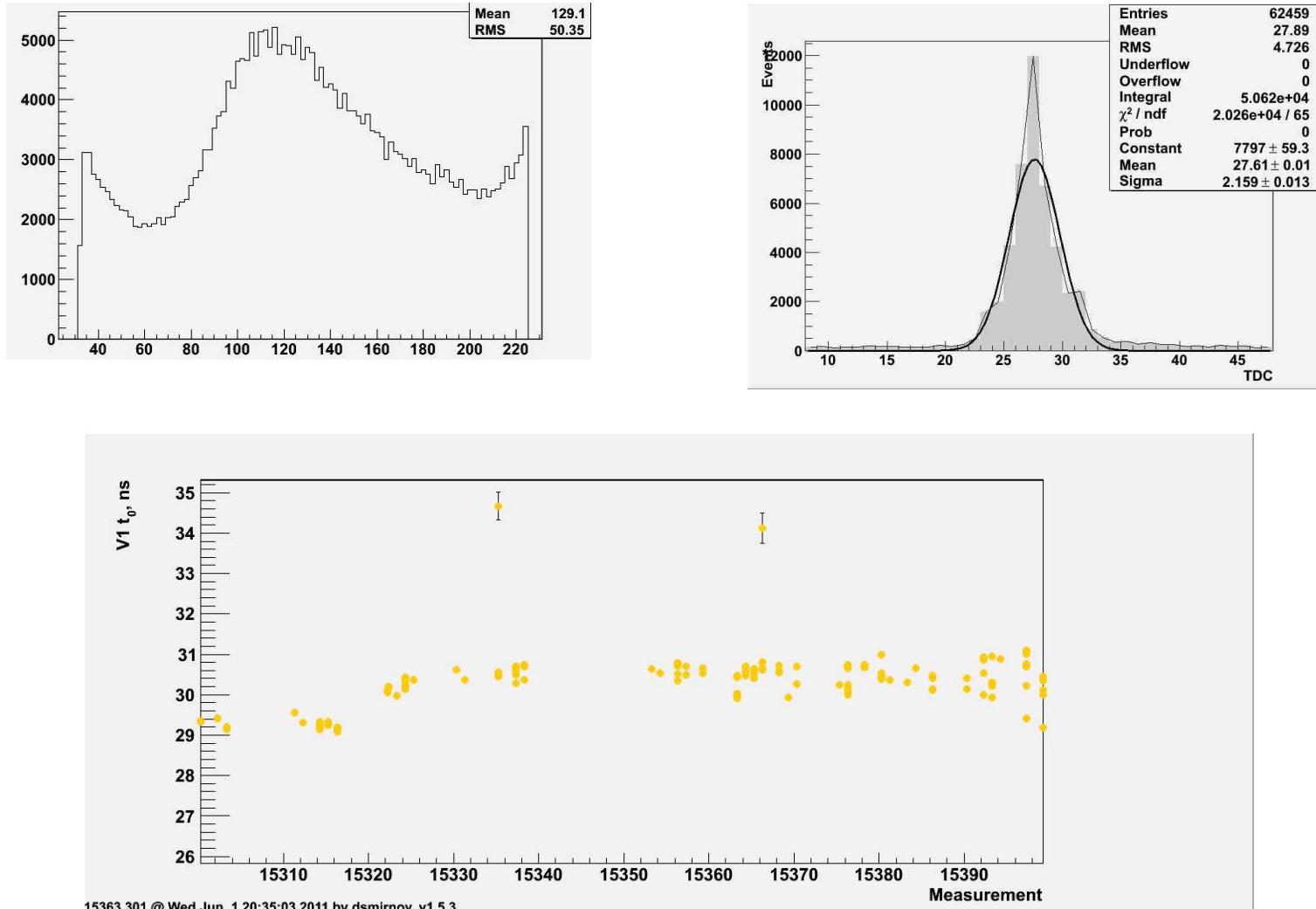
12 of 18



- In 2010 the system was upgraded to address the rate problems
 - Faster current sensitive preamplifiers replaced charge sensitive ones
 - The effective signal width decreased from few 10's ns to ~ 10 ns

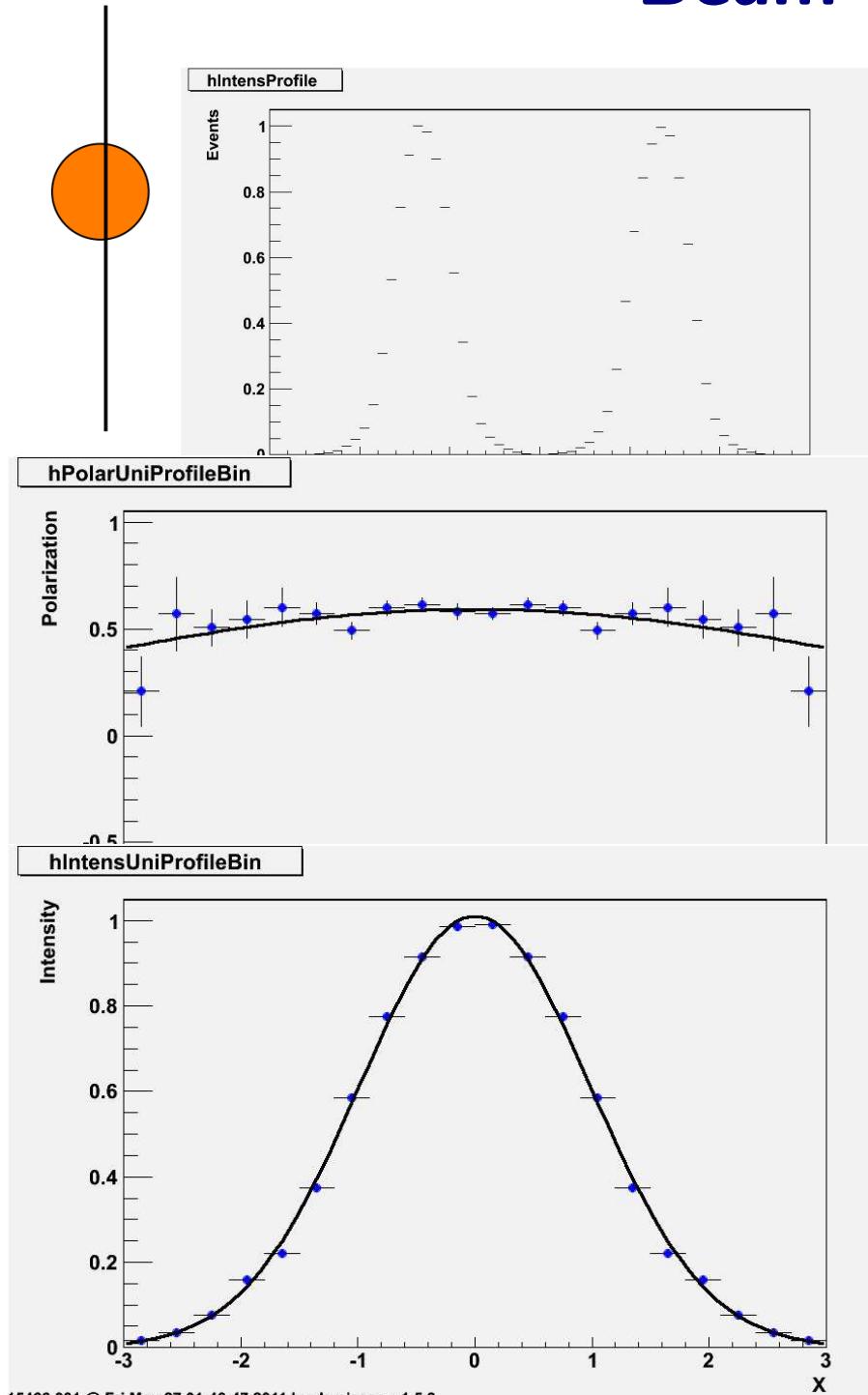
Solving Problems: t_0 Time Offset

- To monitor the time offset t_0 additional scintillators were installed
- The PMT gain is adjusted to match prompt MIPs



- Final conclusion is to be made on the benefits for the future use

Beam Polarization Profile



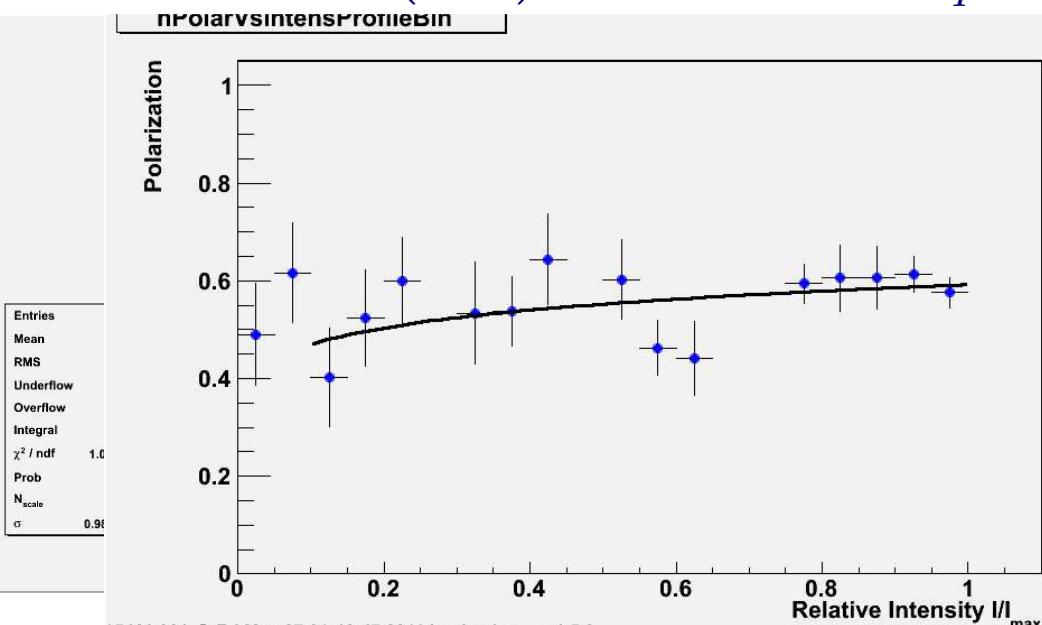
- Precise target position is not necessary if the beam is assumed to have a gaussian profile

$$I(x) = I_{\max} e^{-\frac{x^2}{2\sigma_I^2}}, \quad P(x) = P_{\max} e^{-\frac{x^2}{2\sigma_P^2}}$$

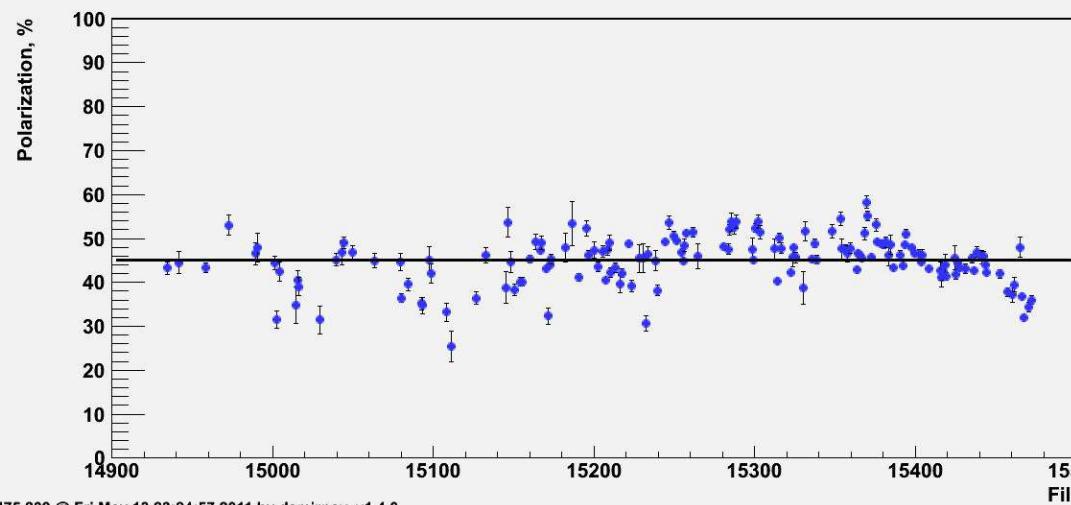
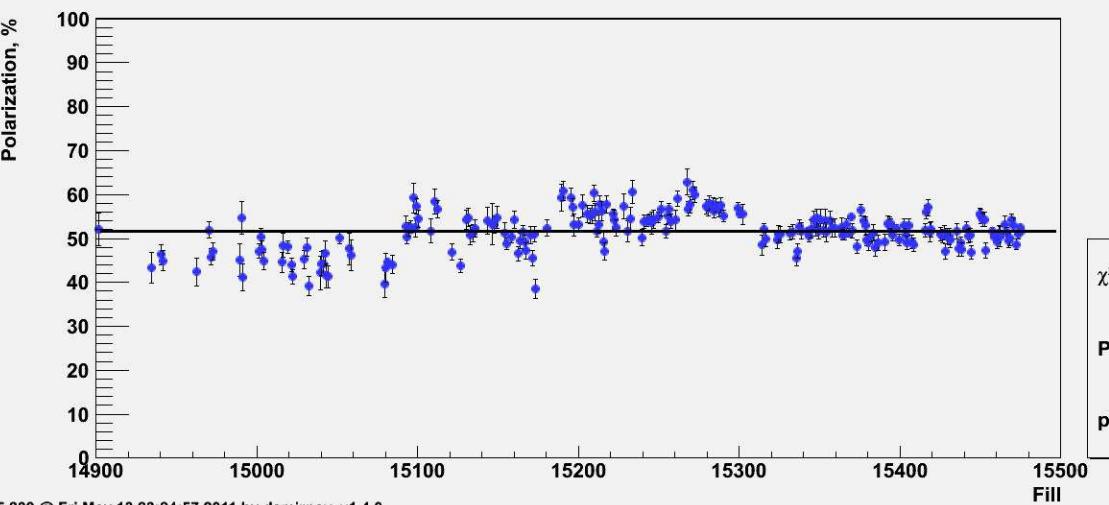
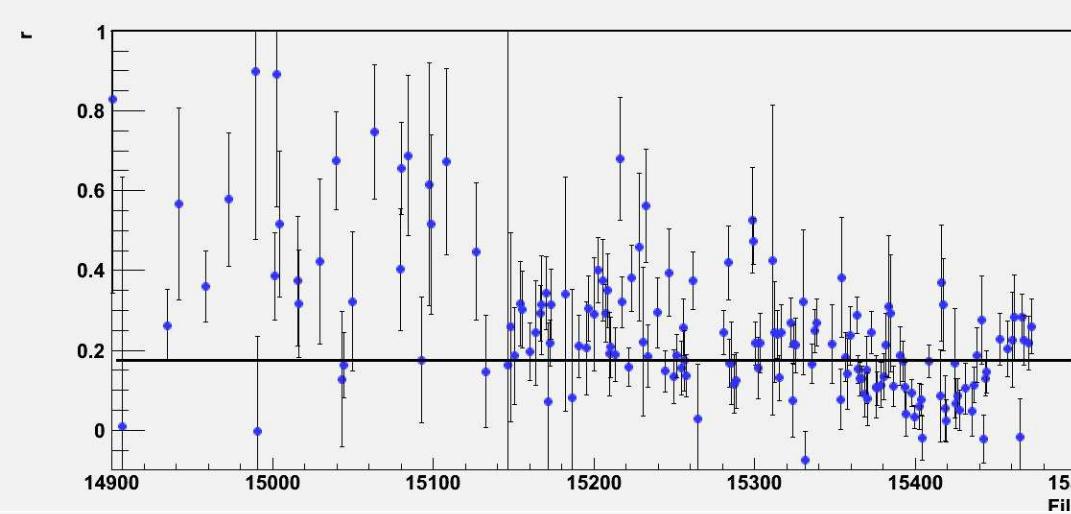
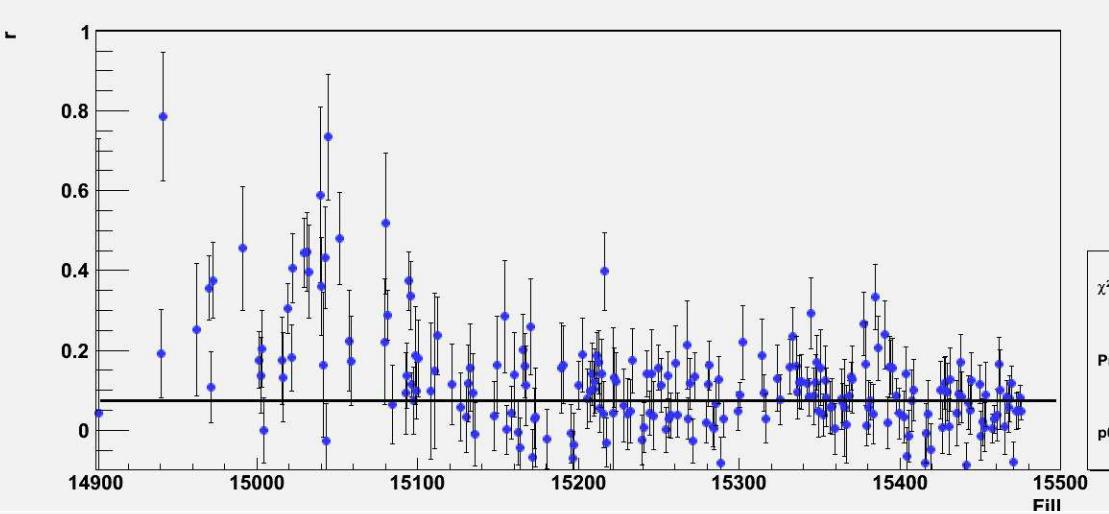
x can be either time or distance

- The intensity and polarization can be related as

$$\frac{P}{P_{\max}} = \left(\frac{I}{I_{\max}} \right)^r \quad \text{with} \quad r = \frac{\sigma_I^2}{\sigma_P^2}$$



Beam Polarization Profile



- The widening of the polarization profile is believed to be one of the main contributors to polarization loss

Overview of RHIC Polarimeters

	H-jet Polarimeter	p-Carbon Polarimeters
Target	Polarized atomic hydrogen gas jet target	Ultra thin carbon ribbon
Detectors	72 silicon strips	96 silicon strips
Calibration	Self-calibrating due to known target polarization	Normalized to H-jet due to lack of direct energy scale calibration
Event Rate	~ 20 Hz Stat. uncertainty ~ 8% in 6–8 hour fill	~ 2 MHz Stat. uncertainty ~ 2% per measurement
Operation	Continuous throughout a store	Few minutes every few hours
Role	<ul style="list-style-type: none"> ● Average beam polarization ● Calibration for other polarimeters 	<ul style="list-style-type: none"> ● Fast online feedback ● Beam profile ● Bunch by bunch polarization ● Store by store polarization for the experiments

Summary

- pp elastic scattering in CNI region is well suit for polarimetry in wide beam energy range
- RHIC polarimeters are non-destructive, unique, and compliment each other
- Upgrade for Run 2011 eliminated some problems
 - The benefit from the prompt monitors is under investigation
- Polarization measurements carried out for the experiments
- Polarimeters provide feedback for the accelerator team:
 - Beam emittance
 - Horizontal and vertical beam polarization profiles
 - Polarization loss in transfer
 - Beam polarization decay
- Currently all polarization measurements rely on the H-jet polarimeter
 - Desired redundancy in polarization measurement can be achieved if p-Carbon polarimeters calibrated by other means
- An ongoing effort aims to better understand the systematic effects in polarization measurements

Igor Alekseev
Elke Aschenauer
Grigor Atoian
Sasha Bazilevsky
Alan Dion
Haixin Huang
Yousef Makdisi
Andrei Poblaguev
Bill Schmidke
Dmitri Smirnov
Dima Svirida
Anatoli Zelenski

[**RHIC Spin Group web page**](#)